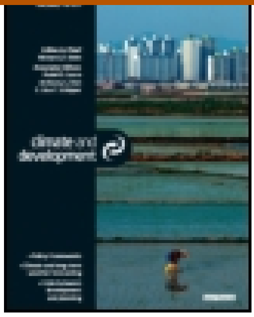

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REVIEW ARTICLE

The utility of weather and climate information for adaptation decision-making: current uses and future prospects in Africa and India

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Developing countries share many common challenges in addressing current and future climate risks. A key barrier to managing these risks is the limited availability of accessible, reliable and relevant weather and climate information. Despite continued investments in Earth System Modelling, and the growing provision of climate services across Africa and India, there often remains a mismatch between available information and what is needed to support on-the-ground decision-making. In this paper, we outline the range of currently available information and present examples from Africa and India to demonstrate the challenges in meeting information needs in different contexts. A review of literature supplemented by interviews with experts suggests that externally provided weather and climate information has an important role in building on local knowledge to shape understanding of climate risks and guide decision-making across scales. Moreover, case studies demonstrate that successful decision-making can be achieved with currently available information. However, these successful examples predominantly use daily, weekly and seasonal climate information for decision-making over short time horizons. Despite an increasing volume of global and regional climate model simulations, there are very few clear examples of long-term climate information being used to inform decisions at sub-national scales. We argue that this is largely because the information produced and disseminated is often ill-suited to inform decision-making at the local scale, particularly for farmers, pastoralists and sub-national governments. Even decision-makers involved in long-term planning, such as national government officials, find it difficult to plan using decadal and multi-decadal climate projections because of issues around uncertainty, risk averseness and constraints in justifying funding allocations on prospective risks. Drawing on lessons learnt from recent successes and failures, a framework is proposed to help increase the utility and uptake of both current and future climate information across Africa and India.

Keywords: climate information services; adaptation; semi-arid regions; barriers; climate risk

1. Introduction

Recent developments in the provision of weather and climate information (Dutton, 2002; Giorgi, Jones, & Asrar, 2009; Hewitt, Mason, & Walland, 2012; IPCC, 2013) have created opportunities to better integrate scientific information into decision-making (e.g. Adams et al., 2015; Hallegatte, 2009; Wilkinson, Budimir, Ahmed, & Ouma, 2015). Furthermore, in the context of a changing climate (IPCC, 2013) and the high exposure of developing countries to climate change risks (Hewitson, & Coauthors, 2014), it is important that long-term planning decisions assess future climate projections to help reduce risks and utilize opportunities.

The relevance of weather and climate information is largely dependent on the ability of scientists to provide information that is fit-for-purpose (Daron, Sutherland, Jack, & Hewitson, 2015; Ranger et al., 2010) and produced in formats that can be integrated into decision-making processes. The relevance of weather and climate information is dictated by the nature of the risks being managed, the economic sector of focus, the region of interest, the governance structures within which decisions are made, and other context-specific realities (Adger et al., 2009; Goddard et al., 2010). In Africa and India, managing weather and climate risks is intrinsically related to the sociocultural context, differential vulnerability and

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economic development pathways (Adger, Huq, Brown, Conway, & Hulme, 2003; Denton, 2002; Spear et al., in press; Ziervogel & Zermoglio, 2009).

We distinguish between scientific information and local knowledge about weather and climate. Local knowledge encompasses 'the knowledge and practices that are acquired by local people over a period of time through the accumulation of experiences over generations, society–nature relationships, and community practices and institutions' (Kniveton et al., 2014, p. 38). Whilst acknowledging the importance of local knowledge in shaping decisions, our focus is on the uptake and use of externally provided scientific weather and climate information, which refers to processed data, products and/or evidence-based knowledge about the atmosphere-ocean system across short (hours to days) and long (seasons to decades) time scales; the term information, as opposed to data, implies that it has meaning and relevance within a given context. It is typically produced and disseminated by scientific institutions such as national meteorological agencies, or intermediaries and boundary organizations (e.g. environmental consultancies, applied university research centres). The private sector has recently become more active in providing short-term forecasts and services. For example, in India, Skymet (http://www.skymet.net/) provides climate services for agriculture risk management, weather forecasting, and crop insurance and delivers short-, medium- and long-term forecasts at the district level to multiple actors.

Many factors affect the uptake and use of weather and climate information. Two key scientific barriers limiting the uptake of long-term climate information in Africa and India are the lack of reliable historical observations (Overpeck, Meehl, Bony, & Easterling, 2011; Tarhule & Lamb, 2003), both to understand the current climate and to evaluate climate models, and the coarse scale of future climate projections (Taylor, Stouffer, & Meehl, 2012). Additional social and economic barriers include socio-cognitive constraints (Jones & Boyd, 2011; Singh, Dorward, & Osbahr, 2016), a disconnect between users and producers of climate information (Lemos, Kirchhoff, & Ramprasad, 2012; Singh, Urquhart, & Kituyi, 2016), and inadequate institutional capacity to effectively deliver and use climate information (Singh, Urquhart, et al., 2016; Spear et al., in press; Tall, Kristjanson, Chaudhury, Mckune, & Zougmore, 2014).

In this paper, examples of how weather and climate information, across temporal and spatial scales, can be successfully integrated into decision-making in Africa and India are provided. Given the importance of agriculture in Africa and India, we focus primarily on the agricultural sector, with some additional examples from the development of early warning systems (EWS). Using this evidence, we extract lessons for improving the utility of climate information to manage present and future climate risks better.

In Section 2, the current landscape of weather and climate information is outlined. Insights from the analysis of literature and relevant projects across Africa and India are provided in Section 3. Key barriers to the utility and uptake of weather and climate information are discussed in Section 4. In this paper, 'utility' refers to the usefulness of climate information in managing risk, and 'uptake' is the use or application of climate information to make decisions. In Section 5, we present a framework to demonstrate how short-term and long-term climate information feeds into decision-making processes at various spatio-temporal scales and conclude by emphasizing key gaps in research, policy and practice in Section 6.

2. Background on weather and climate information

2.1. *The existing landscape of weather and climate information*

Weather and climate information encompasses a diverse range of data sets, methods and tools. To unpack the issues in the utility of weather and climate information for decision-making, it is necessary to understand what type of information is relevant and the underpinning technical and scientific challenges associated with the production of such information. This section summarizes the range of globally and regionally available weather and climate information, but first provides pertinent background on key concepts of weather and climate.

Weather and climate are fundamentally different. Definitions vary (Werndl, 2015), but 'weather' is often defined as the state of the atmosphere at a point in time, while 'climate' is the statistical distribution of weather aggregated over a period of time (e.g. a 30year period: Arguez & Vose, 2011). Atmospheric and ocean processes influence both weather and climate, but different aspects have more or less importance depending on the time scale of interest. Crucially, weather predictions are limited by chaotic behaviour in the atmosphere; a weather forecast (i.e. a deterministic forecast of the future state of the atmosphere) loses all skill beyond a lead time of approximately two weeks (Palmer, 1993). Longer time scale predictions are possible but they must focus on aggregate statistics of weather (i.e. climate). Seasonal forecasts typically estimate the likelihood of a forthcoming season being different to climatology, and multi-decadal climate projections detail possible changes to the statistics of climate processes and variables (e.g. changes in mean annual rainfall). Furthermore, accurate observations of the atmosphere are required to make skilful short-term weather and climate forecasts (Collins, 2002), but become less important for long-term future climate projections (Hawkins & Sutton, 2009). Skilful predictions on longer (climate) time scales result from accurate representations of the slower evolving components of the climate system, such as the oceans and polar ice sheets, as well as changes in the external forcings on the system (e.g. greenhouse gas forcing). The predictability of future weather and climate, as well as our ability to understand past weather and climate, affects the type of information that can be provided.

Historical observations help us understand past and present-day climate risks. Observations from paleoclimate proxy data sets (e.g. from ice cores and tree ring data) and directly measured observational data sets provide data at different temporal and spatial resolutions. For example, three observational data sets are used in the Intergovernmental Panel on Climate Change (IPCC) fifth Assessment Report (AR5) to develop a time series of global mean annual temperatures from 1850 to the present day (Figure SPM1; Stocker, Qin, Plattner, Tignor, & Allen, 2013). Other examples of observational data sets include satellite-based rainfall data (e.g. Huffman et al., 2007) and tropical cyclone data (e.g. Knapp, Kruk, Levinson, Diamond, & Neumann, 2010). In addition, historical model reanalyses developed using General Circulation Models (GCMs) – the same models used in climate prediction – assimilate observations to create spatially consistent data. This is particularly useful in data-sparse regions of the world and for validating climate model outputs.

GCMs are the primary source of future weather and climate information. Many scientific institutions provide global weather and seasonal forecasts, based on GCM output, and there are a number of strategic partnerships between national meteorological agencies in developed and developing countries to share modelling and forecasting capabilities. Advances in understanding and computational capacity have improved the skill of weather forecasts dramatically over recent decades (Lynch, 2008). Seasonal forecasts, however, are generally much less skilful than weather forecasts but they can still have value for guiding management decisions, particularly for agriculture (Troccoli, 2010). Seasonal forecasts are produced using different methods, including GCM-based predictions and empirical statistical methods that are much less computationally expensive.

On longer climate time scales, projections are produced using coupled atmosphere-ocean GCMs and Earth System Models (ESMs), as well as downscaling methods including limited area Regional Climate Models (RCMs) and statistical downscaling techniques. The Coupled Model Intercomparison Project phase 5 (CMIP5) conducted a coordinated set of climate change experiments using the latest generation of GCMs under altered greenhouse gas forcing conditions. The experiments produced twenty-first-century climate projections for potential use in scientific research and policy formation (e.g. IPCC AR5). A similar approach has been adopted to provide higher resolution projections for application in adaptation planning and impacts research. The Coordinated Regional Downscaling Experiment (CORDEX) uses the latest generation of RCMs and statistical downscaling methods to downscale CMIP5 GCM projections to 25–50 km resolution for regions across the world.

In discussing the utility of climate information for decision-making, it is important to distinguish between weather and climate variables (e.g. temperature, winds and rainfall) and climate-related variables that are also influenced by nonclimate drivers (e.g. river flow and soil moisture). Impact models (e.g. hydrological or crop models) can be used to predict changes in climate-related variables and generate information applicable to decision-makers. Like CMIP5 and CORDEX, the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) adopts a consistent experimental framework to provide comparable climate impacts information to different user communities (Warszawski et al., 2014).

Dissemination of climate information has improved in recent times. With an increasing volume of climate data, online data portals are becoming an important mode of communication (Daron, Lorenz, Wolski, Blamey, & Jack, 2015). Institutes across the world host online portals to help users access relevant data and information; examples include the Climate System Analysis Group climate information platform, the Royal Netherlands Meteorological Institute (KNMI) climate explorer, the World Bank climate data portal, and the Potsdam Institute climate impacts platform. Producing information from raw data requires postprocessing expertise and appropriate analytical tools. Users in this space are therefore mostly limited to researchers and impact assessment modellers. However, climate information is increasingly being translated into more usable formats for other users, such as through agro-advisories for farmers (Dorward, Clarkson, & Stern, 2015), and is also being disseminated through innovative communication channels for more widespread uptake. Ensuring the quality, consistency and appropriate interpretation of tailored information represents a continuing challenge for the climate community.

2.2. *Weather and climate information provision in Africa*

Much of the weather and climate information available for Africa comes from global data sets (e.g. CMIP5) and projects with broad geographical coverage (see Section 2.1). In addition, national meteorological and hydrological agencies play an important role in generating and disseminating weather and climate information within African countries (for an overview, see Singh, Urquhart, et al., 2016). While the capacities of different national agencies vary across Africa, typically, they collect and maintain observational data, and provide weather and climate forecasts to communities, private sector companies, and government departments.

Regional hubs, including the Intergovernmental Authority on Development Climate Prediction and Applications

Centre (ICPAC), the Agrometeorology, Hydrology, Meteorology (AGRHYMET) Regional Centre, and the Southern African Development Community Climate Services Centre (SADC-CSC), provide additional support and coordination across countries. ICPAC disseminates early warning climate hazard information to East African countries while AGRHYMET provides information on food security and environmental issues for countries in the Economic Commission of West African States (ECOWAS). Traore et al. (2014) note that because of an increased occurrence of climate extremes throughout West Africa, AGRHYMET has developed additional services, including climate change impact assessments for agriculture and water resources. The SADC-CSC provides climatic information to Southern and Central African countries, covering operational services for climate monitoring, predicting extremes and hydrometeorological products.

The regional centres have a particularly significant role in providing seasonal forecasts at the regional scale, through the Southern Africa Regional Climate Outlook Forum, PRÉvisions Saisonnières en Afrique de l'Ouest for West Africa and the Greater Horn of Africa Regional Climate Outlook Forum (Patt, Ogallo, & Hellmuth, 2007). They create networking opportunities for users of climate information to engage with climate scientists. For example, ICPAC have enhanced collaborations with sector-specific users through pilot projects to develop new tools for supporting the use of weather and climate information in agriculture and food security, livestock, health, water resources, hydropower risk management and environment management. The regional centres also support improving human resource capacity in regional climate modelling, prediction and application.

Long-term climate projections are increasingly being produced through international projects such as CORDEX, and through more engagement of national meteorological agencies in Africa with climate modelling institutions in developed countries. For example, the Global Framework for Climate Services recently developed an initiative called 'Climate Services Adaptation and Disaster Risk Reduction in Africa' to work with national meteorological agencies in Africa and build capacity for improved weather and climate services for agriculture.

2.3. *Weather and climate information provision in India*

Forecasting the Indian Monsoon every year is a challenging task with major implications for short-term adaptation. Weather and climate information generation and dissemination in India are managed by the Earth System Science Organisation (ESSO), New Delhi, which operates as an executive arm of the Ministry of Earth Sciences. Recognizing the importance and relationships between all components of the Earth system, the mandate of ESSO (a virtual organization) is to bring all meteorological and ocean-centric research activities under one umbrella. It has four major branches of Earth sciences: ocean science and technology; atmospheric and climate science; geoscience and technology; and polar science and cryosphere. The ESSO primarily provides services in forecasting the timing and magnitude of monsoon rains as well as other weather and climate variables, the ocean state, and early warnings for natural disasters such as storm surge, earthquakes and tsunamis. The most prominent climate information services provided by a consortium of organizations within the ESSO system are agro-advisories, and hydrometeorological, disaster-related and long-term regional climate projections.

Operational numerical weather forecasting services have improved in recent times due to advances in atmospheric modelling capabilities. India is able to make use of state-of-the-art numerical weather prediction methods and models for near-term weather prediction at the district scale (up to five days). For example, this advancement has enabled tropical cyclone tracking and assessments of the intensity of cyclones over the Bay of Bengal and the Arabian Sea. District-level agro-advisories are prepared for 608 districts across the country using five-day weather forecasts. These forecasts are issued through short messaging services (SMS) every Tuesday and Friday to more than eight million farmers. State Composite Bulletins and National Agrometeorological Advisory Services Bulletins are also issued simultaneously. Weather forecasts are issued at the sub-district level in the country. Hydro-meteorological services are also provided as inputs to the Central Water Commission through their 10 Flood Meteorological Offices established in different parts of India for flood forecasting. In addition, there has been significant improvements in rainfall monitoring and monsoon forecasting activities, with major gains in the accuracy and skill of operational forecasts and heavy rainfall warnings (including using scientific information to set up EWS across sectors and scales). Recently, private climate information service providers have gained prominence in the forecasting space, attributed partly to their vast observational networks and computational facilities (Parija & Mishra, 2015), as well as their flexibility because they are unhampered by constraints that potentially affect government responses.

On climate prediction time scales, the ESSO-IITM ESM has been implemented by transforming the seasonal prediction model to a climate model capable of long-term projections, improving climate prediction capabilities in the region. Simultaneously, regional climate downscaling activities have been institutionalized through CORDEX South Asia.

To improve the efficacy and dissemination of weather and climate information, the Global Information System

Centre in New Delhi has been set up within the framework of World Meteorological Organization Information Systems (WIS). An online WIS portal has been designed for regional and global connectivity to collect and distribute data and information, while also archiving rich data for research and analytical purposes.

3. The use of climate information to inform adaptation decisions: what we can learn from Africa and India

3.1. *Approach to literature reviews and expert interviews*

3.1.1. *Background on the ASSAR project*

The Adaptation at Scale in Semi-arid Regions (ASSAR) project is a five-year-long initiative across Africa and India that focuses on using insights from multiple-scale, interdisciplinary work to improve the understanding of the barriers, enablers and limits to effective, sustained and widespread adaptation out to the 2030s. The ASSAR project ultimately aims to identify scalable adaptation pathways that are responsive to the current and future climatic and non-climatic risks in semi-arid regions. An extensive literature review was undertaken during the diagnostic phase of the project (Few et al., 2015; Padgham et al., 2015; Revi et al., 2015; Spear et al., 2015), and it examined the barriers and enablers for effective medium-term adaptation, including those associated with weather and climate information and their relationship to decision-making. The primary motivation for this paper emerged from identifying, through this process, that the current provision and use of climate information are a critical barrier for adaptation at scale.

3.1.2. *African approach*

The regional approach included an extensive literature review of peer-reviewed articles, reports and policy documents, and tended to focus on the countries ASSAR is working in (Ghana, Mali, Kenya, Ethiopia, Namibia and Botswana). This was supplemented by key informant interviews ($n = 3$) in Botswana and Namibia, including those who specifically work on climate information-based research and associated projects. The key informant interviews were critical to obtain information from multiple perspectives on threats, opportunities and barriers in the climate information space, and to gauge the range of understanding and issues across sectoral subsystems.

3.1.3. *Indian approach*

The IPCC AR5 (Hewitson, & Coauthors, 2014) and national and sub-national literature including peer-reviewed journal articles and book chapters, project reports, and policy documents were reviewed. The review also drew on programmes and assessments conducted by the Government of India as part of India's National Communication to United Nations Framework Convention on Climate Change. This helped to identify key literature and networks associated with climate science, which were followed by interviews with key informants ($n = 8$) with researchers and government officials. The India-specific insights in this paper also draw from discussions in two national stakeholder consultations around climate science and adaptation.

3.2. *Climate information for agriculture in Africa and India*

Agriculture is one of the primary economic sectors in Africa and India, supporting the livelihoods of a large number of people. It is highly exposed to weather and climate risks (Aggarwal, 2008; Cooper et al., 2008; Diao, Hazell, Resnick, & Thurlow, 2007; Kumar, 2011; Mall, Singh, Gupta, Srinivasan, & Rathore, 2006; Schlenker & Lobell, 2010) and transformational changes in some agricultural practices will be required to address the risks of climate change (e.g. through changing crops, Rippke et al., 2016). In particular, agriculture is susceptible to rainfall variability because a substantial portion of agricultural land in Africa and India is inadequately connected to modern irrigation systems. Governments have attempted to minimize impacts through programmatic responses, such as irrigation infrastructure improvements and water storage structures, and, more recently, through the provision of climate information.

Most examples of the successful uptake and use of climate information services have been in helping farmers to find coping strategies for managing short-term climate risks. In some regions, for some agricultural practices, there is widespread uptake of monthly to seasonal climate information (Sivakumar, Collins, Jay, & Hansen, 2014; Stone & Meinke, 2006; Ziervogel & Zermoglio, 2009), largely because of the importance of this time scale for farming decisions (Easterling & Mjelde, 1987; Kandlikar & Risbey, 2000). As evidenced in a study by Cooper et al. (2008), which focuses on rain-fed farming systems in sub-Saharan Africa, the ability of decision-makers to utilize short-term information and manage current climate risks is a precursor to better management of future climate risks. Yet, there are relatively few examples of long-term climate information informing decision-making (Jones et al., 2015; Nidumolu et al., 2016), implying that there are issues around the relevance, provision and usability of climate information on longer time scales.

3.3. *Use of short-term climate information (days to seasons)*

There is a large body of literature in India discussing pilot projects, implemented by state and civil society actors, on the delivery of climate information (mainly short-term weather information) (for examples, see Gadgil, Rao, & Rao, 2002; Sivakumar et al., 2014; Venkatasubramanian, Tall, Hansen, & Aggarwal, 2014), but it is unclear to what extent this information feeds into local and regional decision-making (Manjula & Rengalakshmi, 2015). There is also very little evidence to suggest that long-term climate projections are being integrated into local decision-making. The situation is similar in Africa where there are very few clear examples of climate information uptake, with some notable exceptions in South Africa (e.g. Ziervogel, Johnston, Matthew, & Mukheibir, 2010). However, in recent times, there has been a move towards greater uptake of climate information on shorter time scales (Jones et al., 2015; Stone & Meinke, 2006) through, for example, setting up EWS, planning for resilience in agriculture, and managing water resources by integrating weather and climate information in planning decisions.

In general, decisions taken at multiple levels are a complex interplay of climatic, agronomic, economic and social factors such as labour, individual capacity and credit. Since climate information is often given in isolation, 'more often than not [it] is disconnected from the real life agricultural decisions' (Manjula & Rengalakshmi, 2015, p. 13). Our review identifies characteristics key to defining success in the context of using climate information for decision-making in adaptation: (1) decision-makers (farmers, policy-makers) receive, trust and understand information (Mase & Prokopy, 2014; Singh, Urquhart, et al., 2016); (2) information is locally relevant, fit-for-purpose and available in a timely manner (Lackstrom, Kettle, Haywood, & Dow, 2014; Lobo, Chattopadhyay, & Rao, 2017; Nidumolu et al., 2016; Vaughan & Dessai, 2014); (3) there are appropriate governance and institutional structures for the provision of climate information (Vaughan & Dessai, 2014); and (4) there is an emphasis on socio-economic value in the uptake of climate information provided and subsequent decision-making (Dorward et al., 2015; Nidumolu et al., 2016; Vaughan & Dessai, 2014).

Most examples of success in the uptake and use of climate information to support decision-making have occurred when the provision of relevant climate data is tailored to the local context (specific to biophysical, crop and farmer types) and makes use of innovative delivery processes that are participatory in nature (Table 1). The examples in Table 1 highlight that when climate information is about recent or ongoing stressors (e.g. cyclone in Odisha), it is readily accepted. Information generated through multi-stakeholder processes that involve participatory approaches to interpreting climate information (e.g. Participatory Scenario Planning in Kenya) and those that have direct economic utility for end users (e.g. agrometeorological advisories for crop yields in Maharashtra, India) are found to have local resonance and increased uptake.

3.4. *Use of long-term climate information (years to decades)*

The IPCC AR5 states, with very high confidence, that to adequately assess adaptation options, it is critical to have relevant information about the present and future climate (Klein et al., 2014), implying the need to consider decadal and multi-decadal time scale information. This section describes some examples from India and Africa where long-term climate projections have been used to inform adaptation, but it is important to note that the literature review process revealed that there are very few clear examples of long-term climate information linking directly to on-the-ground decision-making.

In India, a significant effort has been made to generate regional climate projections in the medium term (up to the 2050s) and longer term (up to 2100). The utility of such climate projections, which are at coarser scales than short-term forecasts, has triggered a range of long-term state and non-state responses towards building adaptive capacities and facilitating adaptation in sectors that are likely to be severely impacted by climate change, one of the most prominent being agriculture. It is noteworthy to recognize that the utility of climate projections in the longer time frame is significantly challenged due to the relatively poor performance of climate models in simulating observed historical trends and seasonal dynamics of the summer and winter monsoon (Sabeerali, Rao, Dhakate, Salunke, & Goswami, 2015; Saha, Ghosh, Sahana, & Rao, 2014). This introduces uncertainty around future projections and an element of caution when considering long-term policy responses based on such projections.

Indian climate change scenarios are used to understand impacts on ecological and socio-economic systems for medium- and long-time scales, across subnational and national levels. Using a mix of modelling and field-based experiments, these scenarios are interfaced with key economic sectors to measure the impact of climate change and feedback recommendations. Climate information, coupled with impact assessments and future climate projections, have helped to create a framework that responds to long-term impacts of climate change. For example, land-use/land-cover mapping and biodiversity characterization have resulted in a better understanding of climate change impacts at regional scales (Krishnaswamy, John, & Joseph, 2014) and enabled policy interventions, such as natural resource conservation planning (e.g. Kasturirangan et al., 2013). Rigorous scientific assessments create a basis for initiating large-scale interventions, which are implemented through programme- or policy-based frameworks (such as national Five Year Plans). Impact assessment studies have been anchored within a multi-institutional framework comprising independent and government-sponsored research institutions. Research findings from these centres (either

Table 1. Examples of successful uptake of climate information for short-term decision-making.

India	Africa	Characteristics defining successful use of climate information for adaptation decision-making
Decision analysis framework to communicate seasonal climate forecasts in India (Manjula & Rengalakshmi, 2015) • Participatory approach to communicate forecasts and historical data and help assess trade-offs between competing objectives in a given season using multiple criteria. • Historical data and farmer perceptions and experiences used to build upon terms familiar to farmers, allowing easy comprehension.	*Adaptation Learning Programme (ALP) for Africa* (Ambani & Percy, 2014) *implemented by CARE International, together with the national meteorological services in Ghana, Kenya and Niger* • Multi-stakeholder – Participatory Scenario Planning (PSP). • Multiple information sources - combination of scientific and local forecast knowledge (e.g. based on behaviour of trees, animals and wind patterns) and expertise (what constitutes good rainfall in the local context). • Community monitored rain gauges provide locally relevant data. • Context-relevant information communicated by radio.	**Approach:** Participatory approach to help farmers understand information (e.g. detailed sessions on communicating differences between deterministic and probabilistic forecasts). **Process:** Trust, understanding and capacity to interpret seasonal forecasts is built through engagement including co-exploration of data by different stakeholders. **Particulars:** Provided information is crop-specific and locally relevant. **Utility:** Information tailored around identification of a range of socio-economic benefits, leading to relevant actions that can be taken such as when to plant and what crop to plant.
*Agromet advisories in rural Maharashtra, Watershed Organisation Trust (WOTR) working with the Indian Meteorological Department (IMD) (*WOTR, 2013; Lobo et al., 2017*)* • Forecasts from IMD used to develop context-related, crop-specific agro-advisories. • Advisories include integrated nutrient–water–pest–and diseases management recommendations. • Information dissemination through multiple channels (mobile phones, loudspeakers in the village, on walls in public spaces and word of mouth). • Supplemented with 3-day weather forecasts with special focus on unseasonal rain, frost or temperature spikes.	*CCAA (Climate Change Adaptation in Africa) programme, Kenya jointly funded by IDRC and DFID (2006–2012)* (Ouma et al., 2013) • Traditional forecasters participate in meetings with Meteorology Department and the Kenya Industrial Property Office • Communication through locally established forms of convening the public and mass communication including youth drama on market days or at church. Local public administration officers have executive convening powers for such meetings that attracted crowds. • Local departmental heads interpreting and communicating sector-relevant advisories. • Institutionalizing the entire process of forecast consensus building, development of advisories and communicating the same in the local office of the Kenya Meteorological Department.	**Approach:** Multi-stakeholder, collaborative approach (between meteorologists, agriculture experts, community, NGOs) with use of innovative and multiple modes of communication. Reliability and source of information (from an accepted NGO working in the area for 30 years) strengthen trust in the information. Participation encouraged buy-in and ownership of the resulting consensus forecast to be communicated. **Process:** Advisories are issued in the local language at least twice a week in the summer and more frequently during the agricultural season, giving farmers sufficient time to implement suggested measures. In Kenya, information is communicated through existing sectoral structures, adding value and institutionalization of the process has ensured sustainability **Particulars:** Information communicated in a context-relevant manner – not only is the information relevant but it is readily available, delivered directly to the user. **Utility:** Demonstration of the benefits of agrometeorological advisories through farmer field schools and significant agricultural productivity gains ranging from 30% to 80% (in Maharashtra).

(*Continued*)

Table 1. Continued.

India	Africa	Characteristics defining successful use of climate information for adaptation decision-making
Early warning systems to prepare for cyclones: case of Odisha (Mohanty et al., 2015; *SK Naik,* pers. comm., December 2015) • Three-tier governance system (local, district and state) to deal with disasters like cyclones and typhoons. • Improved forecasting systems (high-accuracy cyclone forecasts were made available at 72 hours in 2009 and 120 hours before in 2013). • Dedicated institutional support for improving forecasting systems, infrastructural strategies (construction of disaster risk mitigation infrastructure) and capacity building (establishing safety and evacuation protocols).	*CCAFS (Climate Change, Agriculture and Food Security) programme, Senegal* (CCAFS, 2015) • Workshops to increase stakeholder awareness about importance of CI in decision-making, familiarize stakeholders with concept of forecasting. • Farmers involved in the process giving input on the packaging and communication of information. • Two weather reports/day – focus on rainfall trends downscaled for the project regions, which was co-produced by CCAFS scientists and the National Meteorological Agency. • Information communicated by radio and SMS on cellular telephones to about 2 million farmers.	**Approach:** Data provided in a way that it reaches timely to vulnerable populations directly and are presented in a way that is understood. Awareness and understanding are built through workshops **Process:** Training of policy-makers to receive and understand information (Odisha) and involvement of farmers in the process help ensure that relevant data are provided (Senegal). **Particulars:** Generation of special warning bulletins and transmission in local languages to the affected areas every hour. **Utility:** No loss of lives in 2013 Cyclone Phailin during which 1 million people were evacuated from 18000 villages to coastal shelters as opposed to 10000 lives lost in 1999. In Senegal, information provided is used to decide on planting dates and crop varieties to be planted. It therefore has a socio-economic benefit through providing increased food security.

independently or through a sponsored assessment) are recognized through a multi-stakeholder engagement process of policy formulation (http://moes.gov.in/programmes/programmes). The cornerstone of the long-term response to climate change in India has been the National Mission for Sustainable Agriculture and a network-based National Initiative on Climate Resilient Agriculture (NICRA) project. Collectively, these programmes aim to make the agricultural sector climate-resilient. Improved climate information has been critical for designing interventions within these programmes.

In Africa, monitoring and assessing the use of long-term climate information are complicated by the paucity of direct engagement with decision-makers. Outside of direct engagement with user communities, it is difficult to establish how information is being used, implying the need for further action research-oriented approaches.

Additional evidence from the literature shows limited use of long-term climate information in Africa with some notable exceptions, particularly in South Africa. For example, historical observations and downscaled climate projections were used as an input to the Long-Term Adaptation Scenarios for the Department of Environmental Affairs (DEA, 2013). The scenarios considered the implications of climate change for a range of sectors to inform government planning decisions. In the City of Cape Town, the Stormwater and Sustainability Branch has adapted to climate change by factoring in an increase in rainfall intensity of 15% based on climate change projection data (Taylor, in press). This has led to an increase in the area designated as high hazard zones and floodplains and a reconsideration of infrastructure specifications such as increasing the diameter of pipes. Also, Daron (2015) examined the use of climate information in local decision-making to protect railway infrastructure in Cape Town. The study shows that sea level rise information and downscaled projections of future winds were considered but that the decision process was far more influenced by other technical and socio-economic factors. Finally, in a review of climate change impacts and adaptation in South Africa, Ziervogel et al. (2014) note that some city-scale and project-based adaptation responses have been implemented, but that institutional challenges persist. The study identifies a number of sectors where long-term climate change and impacts information has been used, for example, in the development of national plans for the expansion of protected areas by the middle of this century (DEAT, SANBI, 2008).

Numerous and significant socio-economic challenges in India and Africa require urgent attention and the long-term nature of climate change has meant that many have not viewed it as central to addressing urgent challenges (Namibia: MET, 2011). There is a growing awareness of the impacts of climate change on poor households, their livelihoods and the rural and urban areas in which they live. Despite this, responding to the impacts has been slow to be institutionalized, as many are uncertain how to adapt (DEA, 2011; Dirkx, Hager, Tadross, Bethune, & Curtis, 2008; Giorgis, 2011) or how to use of climate information in decision-making (Koch, Vogel, & Patel, 2007; Pasquini, Ziervogel, & Cowling, 2013). Climate change information has not been well integrated into national development planning processes or plans in most African countries (Dirkx et al., 2008; Giorgis, 2011).

4. Barriers in the utility and uptake of weather and climate information

Despite the growing volume of climate information across Africa and India (Sections 3.1 and 3.2), there remain substantial gaps between the information held in scientific institutions and that which is required to inform decision-making (Waagsaether & Ziervogel, 2011; Ziervogel & Zermoglio, 2009). While the scientific community continues to improve the coverage and quality of observational networks (e.g. Hou et al., 2014) and advance the skill of forecasts across time scales (Hoskins, 2013), there are numerous scientific and practical barriers which impact the utility and uptake of climate information in India and Africa (Table 2).

Climate information must be locally relevant to be useful in guiding decisions at the local level, as noted in Table 2 with reference to India. However, this does not imply the need for high spatial resolution model data. For example, the baseline climate of two nearby locations may differ (i.e. have different annual mean temperatures and climatologies), but the range of projected climate changes could be the same at both locations (Bunyan, Krishnaswamy, Sanjay, Raskar, & Bazaz, 2015). Furthermore, information on climate phenomena at larger spatial scales can be relevant, but to be usable by decision-makers, the local manifestation of that phenomena must be translated into variables and processes that matter to end users (e.g. in local government), such as implications for local water supplies, floods, or the possibility of heat-stroke. This is evident when we see the discourse in India regarding a recent sustained drought. In this case, coarse spatial scale information about future changes in temperature could still have utility for decision-making at the local level – communicating this in a way that is meaningful for decision-makers is the key challenge to overcome. This illustrates that barriers to uptake of climate information (Table 3) are distinct from barriers in the utility of climate information (Table 2). Yet, both forms of barrier need to be overcome for climate information to be used successfully.

The usability of climate information depends on the level and quality of interaction between information producers and users (Lemos et al., 2012) as well as how the information 'fits' processes of decision-making (Singh, Dorward, et al., 2016). However, there is a big disconnect between knowledge production and its use. There exist significant challenges in the uptake of climate information due to social factors, gaps in capacity and processes to facilitate interpretation of climate information, and limited integration with existing ways people perceive and manage risks (Table 3). Supplementing climate forecasts with historical data may be one way to develop usable climate information for agricultural producers (Dorward et al., 2015; Haigh et al., 2015). To improve information uptake, studies recommend education and outreach (Changnon, 2004; Haigh et al., 2015), demonstrations of the utility of climate forecasts and historical information (Changnon, Sonka, & Hofing, 1988; Haigh et al., 2015), and participatory interpretation of information showing direct links with livelihood outcomes (Dorward et al., 2015; Lobo et al., 2017; Roncoli et al., 2009; Stone & Meinke, 2006).

Crucially, barriers in climate information utility and uptake stem from inadequate understandings around how and why end users make decisions. Research has shown that farmer decision-making is a complex process of iterative adjustments that are mediated by their assets and aspirations, sociocultural and perceptual environments, and larger policy and market regimes (Gbetibouo, 2009; Singh, Dorward, et al., 2016). Agricultural decisions, especially by smallholders, also focus on short time horizons such as seasons and years rather than decadal time scales that impacts of climatic change are typically projected for. Thus, efforts to improve use of weather and climate information need to factor in timing of information delivery in the decision-making cycle (Lobo et al., 2017).

5. Discussion: establishing a framework for integrating short-term and long-term climate information

Confronted with urgent development needs, and in response to proximate risks associated with a variable and changing climate, decision-makers in Africa and India must be guided by currently available climate information to make informed choices, whilst acknowledging that information availability, relevance and usability will always evolve. Examples of the successful use of short-term climate information for adaptation decision-making span multiple sectors and actors, and have seen rapid innovation in information creation and communication (Section 3.3). Long-term information tends to have a *steering* function rather than directly influencing decisions made in response to, or anticipation of, more immediate risks, and therefore examples of long-term climate information being used in decision-making are harder to find. Nevertheless, the lack of successful examples found in this study demonstrates that integrating long-term climate information into decision-making remains a challenge, largely

Table 2. Barriers to utility of weather and climate information (CI).

Barriers	India	Africa
Climate science	• Lack of locally relevant downscaled climate information (Bunyan et al., 2015). • Seasonal climate forecasts are in probabilistic language, which are difficult to understand. Furthermore, they do not provide details like location of rains, the timing, lead times, duration and rainfall volumes which are key to decision-making (Manjula & Rengalakshmi, 2015). • There are difficulties in predicting the NE monsoon accurately (Bunyan et al., 2015), which is crucial for winter crops in southern states, primarily due to complex climatology of the region. The inability to predict the NE monsoon is especially relevant to planning on seasonal time scales.	• Data are sparse in parts of Africa and long-term reliable observations (>30 years) are only present in some countries, such as South Africa. In some regions (e.g. Democratic Republic of Congo), there are no long-term station data sets. • Where models converge, current rainfall trends and physical interpretations often counter IPCC multi-model projections. Model uncertainties constrain adaptation prioritization and improvements in how projection uncertainties are articulated are needed. (Conway & Schipper, 2011). • Many national meteorological agencies lack the skills and capacity to produce CI across multiple timescales, particularly for longer term projections (Ziervogel & Zermoglio, 2009). • The quality and type of information supplied are not sufficient for the complex decision-making needs of end users (USAID, 2014). • Understanding/modelling of key processes, such as the impact of teleconnections (e.g. ENSO) on regional and local climates, remains incomplete, and this impacts the reliability of model projections.
Communication and outreach systems	Poor reach into remote areas and delay in communicating climate information (Manjula & Rengalakshmi, 2015).	Access to relevant CI remains a barrier to some communities and the increase in CI has not been supported by adequate growth in institutional architecture that helps in enabling capacity building to interpret and communicate this information (Ziervogel et al., 2008).
Lack of timely information to the user	The time between short-term forecasts (e.g. heavy rains) and farmer abilities to incorporate these forecasts in their decision-making, is insufficient (Manjula & Rengalakshmi, 2015).	The timing of forecast delivery affects the ability to use it in some policy areas e.g. water and agriculture management (Haigh et al., 2015; Lemos, Finan, Fox, Nelson, & Tucker, 2002). At times, a mismatch is noted in this aspect.
Temporal mismatch	Farmers typically plan on short timescales (1-day to 1-week scale) going up to one season. However, medium- to long-term CI is useful for community-based resources (N. Kumar, pers., comm., December 2014) and needs to be communicated from a longer term perspective.	Planning simultaneously for immediate and long-term adaptation activities is a challenge (Spear et al., 2015; pers. comm. respondent from GIZ Office, Namibia March 2015).

because the information is highly uncertain and, particularly in current formats, harder to integrate into policy-making processes.

Currently, short-term decisions (which utilize weather and seasonal forecasts to manage more immediate risks) are being taken mostly independent of their long-term implications. For systems to transform and become resilient to current and future climate risks, actions that acknowledge short- and long-term implications must converge; actions informed by short-term information without considering the broader long-term implications may be maladaptive (Hallegatte, 2009; Jones, Carabine, & Schipper, 2015).

Combining short- and long-term climate information can contribute to transformative change (Kates, Travis, & Wilbanks, 2012). It can aid decision-making across spatial and temporal scales and start to challenge how risks and uncertainty are perceived, prepared for and managed. Such transformative change has to be understood as an incremental process with actions in the short-term providing the foundation for long-term adaptation, including changing behaviours. Setting up processes, institutions and infrastructure that align short-term and long-term thinking, coupled with improvements in knowledge (both through weather and climate science and through our ability to link it with

Table 3. Barriers to uptake of weather and climate information.

Barriers	India	Africa
Social factors	Men are main 'receivers' of CI because they tend to own mobile phones and interact with extension officers (Singh, 2014). Thus, women within households and women of female-headed households get lower access to CI (Ahmed & Fajber, 2009).	The cultural context is also important to recognize, as extreme events are seen by some to be attributed to 'the hands of the Gods' (Spear et al., 2015). Lack of trust by consumers in the CI availed to them (Haigh et al., 2015).
Capacity to interpret climate information	Only when forecasts (e.g. for deficit seasonal rainfall) are linked to direct impacts (poor germination) and risks to farmer livelihoods, do they result in behavioural shifts (change in sowing time) (Gadgil et al., 2002). Currently, lack of skill in interpreting the forecasts a (Manjula & Rengalakshmi, 2015).	Difficulties in interpreting CI and how climatic conditions interact with non-climatic variables (soil moisture) to affect livelihoods directly (through sowing dates, disease incidence) (Ziervogel et al., 2008). Limited capacity to implement environmental interventions and integration of climate change scenarios into planning (Bourne, Donatti, Holness, & Midgley, 2012 in the Namakwa District Municipality, South Africa; Ziervogel & Zermoglio, 2009).
Lack of linkages with individual perceptions and traditional knowledge	No examples of CI systems in India that demonstrate how diverse knowledge systems can be successfully integrated to improve decision-making. This gap may be because traditional knowledge tends to be held by older member of a community while CI is communicated to 'progressive' or younger farmers (Manjula & Rengalakshmi, 2015).	Perceptions of climate variability as held by farmers may differ from meteorological data and (Osbahr, Dorward, Stern, & Cooper, 2011) this may constrain uptake of CI because of different frames of constructing and planning for uncertainty and risks.
Lack of involvement of all stakeholders	There needs to be involvement and consultation with multiple stakeholders on problem identification, ascertain/generate demand, implementation of interventions (most importantly the local government), which is critical to uptake (N. Kumar, NICRA, pers. comm., December 2014).	Multi-stakeholder participation at different stages of climate information delivery and meaning-making help (Ambani & Percy, 2014).

traditional knowledge), will help improve the utility of climate information for decision-making. The principal objective is to enable behaviour change and improved dialogue across the continuum of knowledge producers, intermediaries that facilitate information flow (for example, extension workers) and end users (Singh, Urquhart, et al., 2016; Waagsaether & Ziervogel, 2011).

Using deductive reasoning, we have developed a framework to institutionalize the combined uptake of short- and long-term climate information. Figure 1 shows a framework for linking short- and long-term climate information with the actions that are motivated at different spatial scales. While there are not many examples of linking decision-making across time scales from the domain of climate services, we draw on experiences from diverse fields such as biodiversity conservation (Krishnaswamy et al., 2014) and watershed development (Badiger et al., 2007) to identify ways in which short-term and long-term information can be leveraged towards transformative change. In the framework, temporal scales are referenced along the x-axis and the y-axis denotes behavioural change as a continuum from coping to adapting.

The proposed framework recognizes cross-scalar flows of information and actions; note that actions at different time scales are concurrent and discrete boxes are used only for visual representation. Also, while the diagram is shown as flat and two-dimensional, we recognize that decision-making using climate information is nested and interlinked, that is, farmer decisions taken both in the short and long term are embedded in national and sub-national policies and opportunities. The framework identifies three main cross-scalar flows (denoted by the numbered two-sided blue arrows in Figure 1) that shape how climate information shapes adaptive behaviour:

(1) *Incremental behavioural shifts*: Short-term climate information, such as weather advisories and seasonal forecasts, helps users to plan for and manage risks in the short term. For example, a weather advisory may help farmers choose to irrigate their crops in the next few days or not. Such short-term decisions help users cope with variability in their day-to-day functioning and contribute to coping capacity. The two-way arrow suggests that long-term climate information also impacts decisions in the short-term. For example, climate projections that demonstrate a warming trend can motivate short-term responses to grow

temperature-tolerant varieties. Examples of this are already being seen in India (Lobo et al., 2017; Manjula & Rengalakshmi, 2015; Nidumolu et al., 2016) and across Africa (Dorward et al., 2015; Ouma, Ogallo, & Onyango, 2013).

(2) *Long-term systemic restructuring*: Medium- to long-term action and investment in setting up and sustaining climate information institutional architecture and infrastructure contribute to restructuring the entire system that is defined as involving producers (what knowledge to produce), communicators (who and what) and users of climate information (when and in what form) – for example, Regional Climate Outlook Forums in Africa. In India, national investments in the mid-2000s helped to develop a robust system of climate information services (producing forecasts, training extension staff, field demonstration through regional agriculture universities) (Singh, Urquhart, et al., 2016) and this slowly fostered recognition of the utility of climate information to manage risk. Today, the benefits of those investments are visible through farmer-led demands of better forecasts, the private sector seeing value in investing in climate information delivery, and integration of climate information in adaptation initiatives (Lobo et al., 2017).

(3) *Event-driven sudden change*: High-impact extreme events (e.g. cyclone in Odisha in 1999, flooding in Mozambique in 2000 and flooding in Mumbai in 2005) motivate swift action in setting up infrastructure (monitoring stations, scientific and modelling capabilities), capacity building (training communities for disaster preparedness and reading early warnings), and once in place, these actions, though done on a short time horizon, can lead to long-term transformative change. For example, in India, the supercyclone in Odisha (1999) led to institutionalizing extensive EWS and inspired a deep perceptual and behavioural change among government staff, civil society and exposed communities.

The framework aims to provide a way forward in demonstrating how actions at one temporal scale are interlinked with actions across different temporal scales. For example, repeated use of seasonal forecasts equips farmers to read and understand shifts in seasons that may lead to a longer term change, such as a change in crops grown (Stone & Meinke, 2006). The Participatory Integrated Climate Services for Agriculture project in East Africa already shows a promising example (Dorward et al., 2015). Also, actions at one spatial scale, or governance level, can impact actions at multiple other scales. For example, in India, a dedicated push towards watershed development at the national level has prioritized water saving behaviour at local levels with potential adaptation co-benefits. Adopting this framework recognizes that resilience to climate variability and change is only achieved by considering how information is utilized at different spatio-temporal scales, by different actors, and towards outcomes. The challenge is to ensure coherency in the

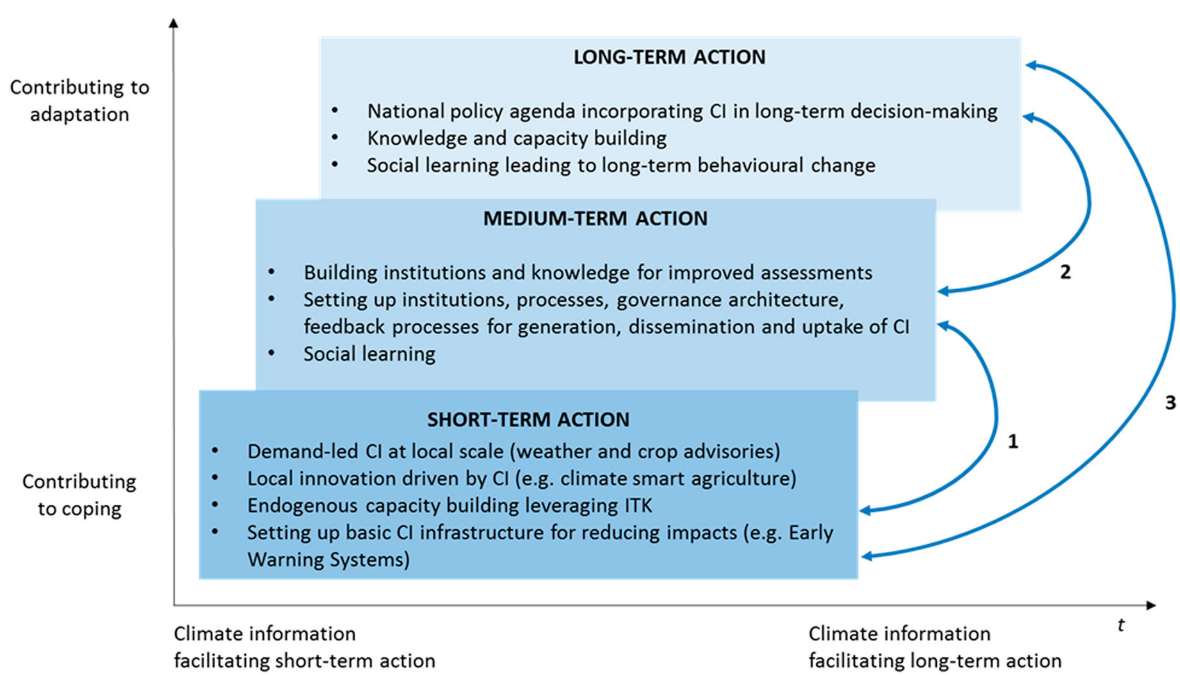

Figure 1. Illustrative framework for using climate information in multi-scalar adaptation decision-making.

production and communication of climate information across multiple scales whilst recognizing the decision-maker's dilemma of addressing climate risks at the same time as addressing non-climate imperatives.

The framework recognizes that short-term information fits with farmer decision-making time scales better (Kandlikar & Risbey, 2000) and can support coping strategies (bottom left box). However, it also argued that, for informing adaptive action, the institutions and demand created for short-term information will have to be leveraged and used to motivate an audience for long-term climate information (upper right box). While the framework identifies synergies between uptakes of short-, mid- and long-term climate information, fructification of such synergies is possible only in an enabling institutional environment. Thus, having *willing* local institutions and government structures with the *capacity* to bridge uptake of short-term and long-term climate information is essential to leverage the gains made in short-term actions to incrementally build towards long-term action and uptake.

6. Conclusions

Drawing on existing literature and expert interviews, we find multiple examples of successful uptake and utilization of short-term climate information in Africa and India, but far fewer examples of explicit traceable use of long-term climate information. Despite the increasing amount of available climate information, and advances in the science, key barriers persist. They include the challenge of considering long-time horizons in managing immediate risks, challenges in assessing the success of integrating long-term climate information, issues around uncertainty and the coarse scale of climate projections, and the lack of institutional capacity to deal with long-term climate risks.

The evidence presented shows that participatory approaches to designing and interpreting climate information promote its uptake for use in decision-making. We also find that, in the context of farming systems, there has been notable traction in developing effective EWS for climate-induced disasters across comparative geographies of Africa and India. Insights and lessons in developing information and warning systems on shorter time scales should inform the type of information that is developed to inform on long-term climate risks. Furthermore, the analysis presented shows that the key enablers for the uptake of climate information are building mutual trust (in the context of information provision and mode of delivery) and contextualizing climate information to local contexts and realities.

Tailored climate products and information are being increasingly recognized as important for enabling climate-resilient decision-making in different sectors, particularly for vulnerable communities such as farmers dependent on rain-fed agriculture systems. As evidenced in this paper, there are many successful examples in Africa and India of tailoring short-term climate information for use in decision-making. Learning from these initiatives and scaling them to incorporate long-term climate information, where relevant, could enable informed climate change adaptation planning whilst recognizing and addressing important short-term needs and stressors. We also present a framework that proposes how short- and long-term weather and climate information can be integrated across spatial scales in a manner where success in using short-term information (e.g. increased recognition of the utility of climate information in decision-making) can be leveraged and fed into building processes for using long-term information in an incremental manner. Through combining information across time scales, decision-makers can implement coping and transformative adaptation strategies, thereby making communities more resilient to both present and future climate risks.

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References

Adams, P., Eitland, E., Hewitson, B., Vaughan, C., Wilby, R., & Zebiak, S. (2015). *Toward an ethical framework for climate services*. A White Paper of the Climate Services Partnership Working Group on Climate Services Ethics. Geneva, Switzerland: Climate Services Partnership. Retrieved from http://www.climate-services.org/wp-content/uploads/2015/09/CS-Ethics-White-Paper-Oct-2015.pdf.

Adger, W. N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D. R., … Wreford, A. (2009). Are there social limits to adaptation to climate change? *Climatic Change*, *93*(3–4), 335–354.

Adger, W. N., Huq, S., Brown, K., Conway, D., & Hulme, M. (2003). Adaptation to climate change in the developing world. *Progress in Development Studies*, *3*(3), 179–195.

Aggarwal, P. K. (2008). Global climate change and Indian agriculture: Impacts, adaptation and mitigation. *Indian Journal of*

Agricultural Sciences, *78*(11), 911. http://doi.org/10.1002/ieam.1253.

Ahmed, S., & Fajber, E. (2009). Engendering adaptation to climate variability in Gujarat, India. *Gender & Development*, *17*(1), 33–50.

Ambani, M., & Percy, F. (2014). *Facing uncertainty: The value of climate information for adaptation, risk reduction and resilience in Africa*. Nairobi: Adaptation Learning Programme (ALP) for Africa, CARE International.

Arguez, A., & Vose, R. S. (2011). The definition of the standard WMO climate normal: The key to deriving alternative climate normals. *Bulletin of the American Meteorological Society*, *92*(6), 699–704.

Badiger, S., Lele, S., Ananda, G., Vadivelu, R., Madhavi, L. G., Praveen, G. S., & Praveen, P. (2007). *Long-term and large-scale impacts of watershed development in dry and semi-arid regions of south-central India*. Bangalore: CISED Report, Centre for Interdisciplinary Studies in Environment and Development.

Bourne, A., Donatti, C., Holness, S., & Midgley, G. (2012). *Climate change vulnerability assessment for the Namakwa District Municipality.* Cape Town: Conservation South Africa, 108 pp.

Bunyan, M., Krishnaswamy, J., Sanjay, J., Raskar, V., & Bazaz, A. (2015). Climate change trends and projections. In A. Revi, A. Bazaz, J. Krishnaswamy, R. Bendapudi, M. D'souza, & S. Pahwa Gajjar (Eds.), *Vulnerability and adaptation to climate change in semiarid areas in India* (pp. 32–41). ASSAR Working Paper. Cape Town, South Africa: ASSAR PMU.

CCAFS. (2015). *The impact of climate information services in Senegal*. CCAFS Outcome Study No. 3. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Changnon, S. A. (2004). Changing uses of climate predictions in agriculture: Implications for prediction research, providers, and users. *Weather and Forecasting*, *19*, 606–613.

Changnon, S. A., Sonka, S. T., & Hofing, S. (1988). Assessing climate information use in agribusiness. Part I: Actual and potential use and impediments to usage. *Journal of Climate*, *1*(8), 757–765.

Collins, M. (2002). Climate predictability on interannual to decadal time scales: The initial value problem. *Climate Dynamics*, *19*(8), 671–692.

Conway, D., & Schipper, E. L. F. (2011). Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. *Global Environmental Change*, *21*, 227–237.

Cooper, P. J. M., Dimes, J., Rao, K. P. C., Shapiro, B., Shiferaw, B., & Twomlow, S. (2008). Coping better with current climatic variability in the rainfed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems & Environment*, *126*(1), 24–35.

Daron, J. D. (2015). Challenges in using a robust decision making approach to guide climate change adaptation in South Africa. *Climatic Change*, *132*(3), 459–473.

Daron, J. D., Lorenz, S., Wolski, P., Blamey, R. C., & Jack, C. (2015). Interpreting climate data visualisations to inform adaptation decisions. *Climate Risk Management*, *10*, 17–26.

Daron, J. D., Sutherland, K., Jack, C., & Hewitson, B. C. (2015). The role of regional climate projections in managing complex socioecological systems. *Regional Environmental Change*, *15*(1), 1–12.

DEA (Department of Environmental Affairs). (2013). *Long Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa*. Summary for Policy Makers. Pretoria, South Africa.

DEAT, SANBI. (2008). *National protected area expansion strategy for South Africa*. Pretoria: South African National Biodiversity Institute (SANBI).

Denton, F. (2002). Climate change vulnerability, impacts, and adaptation: Why does gender matter? *Gender & Development*, *10*(2), 10–20.

Department of Environmental Affairs (DEA). (2011). *South Africa Second National Communication to the United Nations Framework Convention on Climate Change* (pp. 1–271). Pretoria: Republic of South Africa.

Diao, X., Hazell, P. B., Resnick, D., & Thurlow, J. (2007). *The role of agriculture in development: Implications for Sub-Saharan Africa.* International Food Policy Research Institute Research Report, 153.

Dirkx, E., Hager, C., Tadross, M., Bethune, S., & Curtis, B. (2008). *Climate change vulnerability and adaptation assessment: Namibia*. Final Report March 2008. Desert Research Foundation of Namibia and Climate Systems Analysis Group for the Ministry of Environment and Tourism, Windhoek, p. 149.

Dorward, P., Clarkson, G., & Stern, R. (2015). *Participatory integrated climate services for agriculture (PICSA): Field manual*. Reading, UK: Walker Institute, University of Reading. ISBN: 9780704915633.

Dutton, J. A. (2002). Opportunities and priorities in a new era for weather and climate services. *Bulletin of the American Meteorological Society*, *83*(9), 1303–1311.

Easterling, W. E., & Mjelde, J. W. (1987). The importance of seasonal climate prediction lead time in agricultural decision making. *Agricultural and Forest Meteorology*, *40*(1), 37–50.

Few, R., Satyal, P., McGahey, D., Leavy, J., Budds, J., Assen, M., … Bewket, W. (2015). *Vulnerability and adaptation to climate change in semi-arid areas in East Africa*. Cape Town, South Africa: ASSAR Working Paper, ASSAR PMU, South Africa, 111 pp.

Gadgil, S., Rao, P. S., & Rao, K. N. (2002). Use of climate information for farm-level decision making: Rainfed groundnut in southern India. *Agricultural Systems*, *74*(3), 431–457.

Gbetibouo, G. A. (2009). *Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa*. Discussion Paper 00849. Washington, DC: International Food Policy Research Institute (IFPRI).

Giorgi, F., Jones, C., & Asrar, G. R. (2009). Addressing climate information needs at the regional level: The CORDEX framework. *World Meteorological Organization (WMO) Bulletin*, *58*(3), 175–183.

Giorgis, D. (2011). *Design of an improved climate risk management early warning system (EWS) and EWS information centres*. InterSouth Development Consultants. Ministry of Environment and Tourism and United Nations Development Programme as part of the Africa Adaptation Project, Namibia, Windhoek, 55 pp.

Goddard, L., Aitchellouche, Y., Baethgen, W., Dettinger, M., Graham, R., Hayman, P., … Meinke, H. (2010). Providing seasonal-to-interannual climate information for risk management and decision making. *Procedia Environmental Sciences*, *1*, 81–101.

Haigh, T., Takle, E., Andresen, J., Widhalm, M., Stuart, C. J., & Ange, l. J. (2015). Mapping the decision points and climate information use of agricultural producers across the US Corn Belt. *Climate Risk Management*, *7*, 20–30.

Hallegatte, S. (2009). Strategies to adapt to an uncertain climate change. *Global Environmental Change*, *19*, 240–47. doi:10.1016/j.gloenvcha.2008.12.003.

Hawkins, E., & Sutton, R. (2009). The potential to narrow uncertainty in regional climate predictions. *Bulletin of the American Meteorological Society*, *90*(8), 1095–1107.

Hewitt, C., Mason, S., & Walland, D. (2012). The global framework for climate services. *Nature Climate Change*, *2*(12), 831–832.

Hewitson, B. C., & Coauthors, Regional context. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. In V. R. Barros et al., (Eds.), *Part B: Regional Aspects: Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change* (pp. 1133–1197). New York: Cambridge University Press.

Hoskins, B. (2013). The potential for skill across the range of the seamless weather-climate prediction problem: A stimulus for our science. *Quarterly Journal of the Royal Meteorological Society*, *139*, 573–584.

Hou, A. Y., Kakar, R. K., Neeck, S., Azarbarzin, A. A., Kummerow, C. D., Kojima, M., … Iguchi, T. (2014). The global precipitation measurement mission. *Bulletin of the American Meteorological Society*, *95*(5), 701–722.

Huffman, G. J., Bolvin, D. T., Nelkin, E. J., Wolff, D. B., Adler, R. F., Gu, G., … Stocker, E. F. (2007). The TRMM multisatellite precipitation analysis (TMPA): Quasiglobal, multiyear, combined-sensor precipitation estimates at fine scales. *Journal of Hydrometeorology*, *8*(1), 38–55.

IPCC. (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *The physical science basis: Intergovernmental Panel on Climate Change, Working Group I Contribution to the IPCC Fifth Assessment Report (AR5)* (1535 pp). New York, NY: Cambridge University Press. doi:10.1017/CBO9781107415324

Jones, L., & Boyd, E. (2011). Exploring social barriers to adaptation: Insights from Western Nepal. *Global Environmental Change*, *21*(4), 1262–1274.

Jones, L., Carabine, E., & Schipper, E. L. F. (2015). *(Re)conceptualising maladaptation in policy and practice: Towards an evaluative framework*. London, UK: PRISE Working Paper.

Jones, L., Dougill, A., Jones, R. G., Steynor, A., Watkiss, P., Kane, C., … Vincent, K. (2015). Ensuring climate information guides long-term development. *Nature Climate Change*, *5*(9), 812–814.

Kandlikar, M., & Risbey, J. (2000). Agricultural impacts of climate change: If adaptation is the answer, what is the question? *Climatic Change*, *45*(3), 529–539.

Kasturirangan, K., Babu, C. R., Mauskar, J. M., Chopra, K., Kishwan, J., Shanar, D., … Chandrasekharan, I. (2013). *Report of the high level working group on Western Ghats* (Vol. I). New Delhi: Ministry of Environment and Forests, Government of India.

Kates, R. W., Travis, W. R., & Wilbanks, T. J. (2012). Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences*, *109*(19), 7156–7161.

Klein, R. J. T., Midgley, G. F., Preston, B. L., Alam, M., Berkhout, F. G. H., Dow, K., & Shaw, M. R. (2014). Adaptation opportunities, constraints, and limits. Climate Change 2014: Impacts, Adaptation, and Vulnerability. In C. B. Field et al., (Eds.), *Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change* (pp. 899–943). New York, NY: Cambridge University Press.

Knapp, K. R., Kruk, M. C., Levinson, D. H., Diamond, H. J., & Neumann, C. J. (2010). The international best track archive for climate stewardship (IBTrACS) unifying tropical cyclone data. *Bulletin of the American Meteorological Society*, *91*(3), 363–376.

Kniveton, D., Visman, E., Tall, A., Diop, M., Ewbank, R., Njoroge, E., & Pearson, L. (2014). Dealing with uncertainty: Integrating local and scientific knowledge of the climate and weather. *Disasters*, *39*(1), 35–53.

Koch, I. C., Vogel, C., & Patel, Z. (2007). Institutional dynamics and climate change adaptation in South Africa. *Mitigation and Adaptations Strategies for Global Change*, *12*, 323–324.

Krishnaswamy, J., John, R., & Joseph, S. (2014). Consistent response of vegetation dynamics to recent climate change in tropical mountain regions. *Global Change Biology*, *20*(1), 203–215.

Kumar, K. S. K. (2011). Climate sensitivity of Indian agriculture: Do spatial effects matter? *Cambridge Journal of Regions, Economy and Society*, *4*(2), 221–235. http://doi.org/10.1093/cjres/rsr004.

Lackstrom, K., Kettle, N. P., Haywood, B., & Dow, K. (2014). Climate-sensitive decisions and time frames: A cross-sectoral analysis of information pathways in the Carolinas. *Weather, Climate and Society*, *6*, 238–252.

Lemos, M. C., Finan, T. J., Fox, R. W., Nelson, D. R., & Tucker, J. (2002). The use of seasonal climate forecasting in policymaking: Lessons from Northeast Brazil. *Climatic Change*, *55*, 479–507.

Lemos, M. C., Kirchhoff, C. J., & Ramprasad, V. (2012). Narrowing the climate information usability gap. *Nature Climate Change*, *2*, 789–794.

Lobo, C., Chattopadhyay, N., & Rao, K. (2017). Making smallholder farming climate-smart. *Economic and Political Weekly*, *LII*, 53–58.

Lynch, P. (2008). The origins of computer weather prediction and climate modeling. *Journal of Computational Physics*, *227*(7), 3431–3444.

Mall, R. K., Singh, R., Gupta, A., Srinivasan, G., & Rathore, L. S. (2006). Impact of climate change on Indian agriculture: A review. *Climatic Change*, *78*(2–4), 445–478.

Manjula, M., & Rengalakshmi, R. (2015). *Seasonal climate information for ensuring agricultural sustainability and food security of smallholder Rainfed farmers: Experience from India*. Chennai: MS Swaminathan Research Foundation.

Mase, A. S., & Prokopy, L. S. (2014). Unrealized potential: A review of perceptions and use of weather and climate information in agricultural decision making. *Weather, Climate and Society*, *6*, 47–61.

MET (Ministry of Environment and Tourism). (2011). *Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC)*. Windhoek: Republic of Namibia.

Mohanty, U. C., Osuri, K. K., Tallapragada, V., Marks, F. D., Pattanayak, S., Mohapatra, M., … Niyogi, D. (2015). A great escape from the Bay of Bengal 'Super Sapphire–Phailin' tropical cyclone: A case of improved weather forecast and societal response for disaster mitigation. *Earth Interactions*, *19*(17), 1–11.

Nidumolu, U. B., Lubbers, M., Kanellopoulos, A., van Ittersum, M. K., Kadiyala, D. M., & Sreenivas, G. (2016). Engaging farmers on climate risk through targeted integration of bio-economic modelling and seasonal climate forecasts. *Agriculture Systems*, *149*, 175–184. doi:10.1016/j.agsy.2016.09.011.

Osbahr, H., Dorward, P., Stern, R., & Cooper, S. (2011). Supporting agricultural innovation in Uganda to respond to climate risk: Linking climate change and variability with farmer perceptions. *Experimental Agriculture*, *47*(02), 293–316.

Ouma, G., Ogallo, L., & Onyango, M. (2013). *Coping with local disasters using Indigenous knowledge: Experiences from Nganyi Community of Western Kenya*. LAP Lambert Academic Publishing. ISBN 978-3-659-45101-0.

Overpeck, J. T., Meehl, G. A., Bony, S., & Easterling, D. R. (2011). Climate data challenges in the 21st century. *Science*, *331*(6018), 700–702.

Padgham, J., Abubakari, A., Ayivor, J., Dietrich, K., Fosu-Mensah, B., Gordon, C., … Echeverría, D. (2015). *Vulnerability and adaptation to climate change in the semi-arid regions of West Africa*. ASSAR Working Paper, Cape Town, South Africa. 190 pp.

Palmer, T. N. (1993). Extended-range atmospheric prediction and the Lorenz model. *Bulletin of the American Meteorological Society*, *74*(1), 49–65.

Parija, P., & Mishra, P. (2015). India Government wrong on monsoon rains, top forecaster says. *Bloomberg*, 26 June. http://www.bloomberg.com/news/articles/20150625/dontbeawetblanketonindiasmonsoontopfore castersays.

Pasquini, L., Ziervogel, G., & Cowling, R. (2013). Facing the heat: Barriers to mainstreaming climate change adaptation in local government in the Western Cape Province, South Africa. *Habitat International*, *40*, 225–232.

Patt, A. G., Ogallo, L., & Hellmuth, M. (2007). Learning from 10 years of climate outlook forums in Africa. *Science*, *318* (5847), 49–50.

Ranger, N., Millner, A., Dietz, S., Fankhauser, S., Lopez, A., & Ruta, G. (2010). Adaptation in the UK: A decision-making process. *Environment Agency Policy Brief*. Retrieved from https://www.theccc.org.uk/archive/aws2/ASC/Ranger%20et%20al%20policy%20brief.pdf.

Revi, A., Bazaz, A., Krishnaswamy, J., Bendapudi, R., D'Souza, M., & Pahwa Gajjar, S. (2015). *Vulnerability and adaptation to climate change in semi-arid areas in India*. ASSAR Working Paper, ASSAR PMU, South Africa. 207 pp.

Rippke, U., Ramirez-Villegas, J., Jarvis, A., Vermeulen, S. J., Parker, L., Mer, F., … Howden, M. (2016). Timescales of transformational climate change adaptation in sub-Saharan African agriculture. *Nature Climate Change 6*, 605–609. doi:10.1038/nclimate2947.

Roncoli, C., Jost, C., Kirshen, P., Sanon, M., Ingram, K. T., Woodin, M., … Yaka, P. (2009). From accessing to assessing forecasts: An end-to-end study of participatory climate forecast dissemination in Burkina Faso (West Africa). *Climatic Change*, *92*(3–4), 433–460.

Sabeerali, C. T., Rao, S. A., Dhakate, A. R., Salunke, K., & Goswami, B. N. (2015). Why ensemble mean projection of South Asian monsoon rainfall by CMIP5 models is not reliable? *Climate Dynamics*, *45*(1–2), 161–174.

Saha, A., Ghosh, S., Sahana, A. S., & Rao, E. P. (2014). Failure of CMIP5 climate models in simulating post-1950 decreasing trend of Indian monsoon. *Geophysical Research Letters*, *41* (20), 7323–7330.

Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, *5*(1), 014010.

Singh, C. (2014). *Understanding water scarcity and climate variability: A study of farmer vulnerability and response strategies in northwest India*. Doctoral Thesis, University of Reading, UK.

Singh, C., Dorward, P., & Osbahr, H. (2016). Developing a holistic approach to the analysis of farmer decision-making: Implications for adaptation policy and practice in developing countries. *Land Use Policy*, *59*, 329–343.

Singh, C., Urquhart, P., & Kituyi, E. (2016). *From pilots to systems: Barriers and enablers to scaling up the use of climate information services in smallholder farming communities*. CARIAA working paper #3. Collaborative adaptation research initiative in Africa and Asia, IDRC, Ottawa, Canada.

Sivakumar, M. V. K., Collins, C., Jay, A., & Hansen, J. (2014). *Regional priorities for strengthening climate services for farmers in Africa and South Asia*. CCAFS Working Paper No. 71. Copenhagen, Denmark.

Spear, D., Baudoin, M.-A., Hegga, S., Zaroug, M., Okeyo, A., & Haimbili, E. (2015). *Vulnerability and adaptation to climate change in semi-arid areas in Southern Africa*. Adaptation at Scale in Semi-Arid Regions (ASSAR), ASSAR working paper. Cape Town: University of Cape Town.

Spear, D., Zaroug, M. A. H., Daron, J. D., Jarre, A., Roux, J.-P., Haimbili, E. N., … Angula, M. N. (in press). Vulnerability and responses to climate change in Namibia. *WIREs Climate Change*.

Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., … Midgley, P. M. (2013). *Climate change 2013: The physical science basis: Intergovernmental Panel on Climate Change, Working Group I Contribution to the IPCC Fifth Assessment Report (AR5)*. New York: Cambridge University Press.

Stone, R. C., & Meinke, H. (2006). Weather, climate, and farmers: An overview. *Meteorological Applications*, *13*, 7–20. doi:10.1017/s1350482706002519.

Tall, A., Kristjanson, P., Chaudhury, M., Mckune, S., & Zougmore, R. (2014). *Who gets the Information? Gender, power and equity considerations in the design of climate services for farmers*. Copenhagen, Denmark: CCAFS Working Paper No. 89.

Tarhule, A., & Lamb, P. J. (2003). Climate research and seasonal forecasting for West Africans: Perceptions, dissemination, and use? *Bulletin of the American Meteorological Society*, *84*(12), 1741–1759.

Taylor, A. (in press). Managing stormwater and flood risk in a changing climate: Charting urban adaptation pathways. In H. Davies, M. New, & D. Scott (Eds.), *Urban development and climate change: Lessons from Cape Town*. Cape Town: UCT Press.

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, *93*(4), 485–498.

Traore, S. B., Ali, A., Tinni, S. H., Samake, M., Garba, I., Maigari, I., … Dieye, P. O. (2014). Agrhymet: A drought monitoring and capacity building center in the West Africa region. *Weather and Climate Extremes*, *3*, 22–30.

Troccoli, A. (2010). Seasonal climate forecasting. *Meteorological Applications*, *17*(3), 251–268.

USAID. (2014). *Assessing Mali's Direction Nationale de la Meteorologie Agrometeorological Advisory Program*. Preliminary Report on the Climate Science and Farmer Use of Advisories. Edited by Edward Carr, 178 pp.

Vaughan, C., & Dessai, S. (2014). Climate services for society: Origins, institutional arrangements, and design elements for an evaluation framework. *Wiley Interdisciplinary Reviews: Climate Change*, *5*, 587–603.

Venkatasubramanian, K., Tall, A., Hansen, J., & Aggarwal, P. K. (2014). *Assessment of India's integrated agrometeorological advisory service program from a farmer perspective*. CCAFS Working Paper no. 54. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Retrieved from www.ccafs.cgiar.org.

Waagsaether, K., & Ziervogel, G. (2011). Bridging the communication Gap: An exploration of the climate science-water management interface. *Environment: Science and Policy for Sustainable Development*, *53*(3), 32–44. doi:10.1080/00139157.2011.570647.

Warszawski, L., Frieler, K., Huber, V., Piontek, F., Serdeczny, O., & Schewe, J. (2014). The InterSectoral Impact Model Intercomparison Project (ISI–MIP): Project framework. *Proceedings of the National Academy of Sciences*, *111*(9), 3228–3232.

Werndl, C. (2015). On defining climate and climate change. *The British Journal for the Philosophy of Science*. doi:10.1093/bjps/axu048

Wilkinson, E., Budimir, M., Ahmed, A. K., & Ouma, G. (2015). *Climate information and services in BRACED countries*. BRACED Resilience Intel, Issue 1, December. Retrieved from http://www.odi.org/sites/odi.org.uk/files/odiassets/publicationsopinionfiles/10107.pdf.

WOTR. (2013). *AGRO-MET weather-based, crop and locale-specific agro-advisories serving farmers of rural Rainfed regions*. Retrieved from http://www.wotr.org/sites/default/files/AGROMET6.9.13.pdf.

Ziervogel, G., Cartwright, A., Tas, A., Adejuwon, J., Zermoglio, F., Shale, M., & Smith, B. (2008). *Climate change and adaptation in African agriculture*. Oxford, UK: Stockholm Environment Institute.

Ziervogel, G., Johnston, P., Matthew, M., & Mukheibir, P. (2010). Using climate information for supporting climate change adaptation in water resource management in South Africa. *Climatic Change*, *103*(3–4), 537–554.

Ziervogel, G., New, M., Archer van Garderen, E., Midgley, G., Taylor, A., Hamann, R., … Warburton, M. (2014). Climate change impacts and adaptation in South Africa. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(5), 605–620.

Ziervogel, G., & Zermoglio, F. (2009). Climate change scenarios and the development of adaptation strategies in Africa: Challenges and opportunities. *Climate Research*, *40*(2–3), 133–146.